MANAGEMENT OF WATER STATUS IN VINEYARDS: META-ANALYSIS OF ITS EFFECTS ON YIELD AND GRAPE COMPOSITION.

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Abstract:

Context and purpose of the study

Mediterranean vineyards have been traditionally grown under rainfed conditions, but in recent decades the irrigated area has increased significantly, seeking to minimize the adverse effects of severe water stress on grape quality and yield. Given the large area occupied by vineyards, and the increasing scarcity of water resources, it is necessary to develop strategies for the optimization and efficient use of water to reduce the risk of its overexploitation. The present study aims at valorizing previous knowledge generated in different research projects by means of a meta-analysis of the effects of water status management on vineyard performance.

Material and methods

A database compiling around 1,400 replicates belonging to 41 water management trials conducted in Spain between 1996 and 2020, covering a wide range of soil and climatic conditions, was used. Each replicate was classified by its level of water stress as No Stress (>-0.411 MPa), Mild (-0.674 to -0.411 MPa), Moderate (-0.936 to -0.674 MPa), High (-1.2 to -0.936 MPa), and Severe (<-1.2 MPa), using their stem water potential values averaged over the season. The mean response ratios and the proportion of change produced by the increase in water stress on vegetative development, yield and grape composition were evaluated.

Results

Changes in plant water status caused significant differences in the parameters analyzed, regardless of the starting stress level, although these patterns varied depending on the specific parameter being analyzed. Thus, the change in pruning wood weight and yield with increasing stress ranged from -5% to -26%, with the greatest changes occurring from moderate to high stress. The changes in soluble solids content of berries ranged from +0.4% to +1.5% with increasing stress, except when increasing from moderate to high stress (-0.74%). In the case of titratable acidity, the change from increasing from a high level of stress to a severe one was +1.4%, while in all other cases it decreased (between -2.6% and -5.2%). The results showed the overall impact of plant water status management in the vineyard performance and constitute a valuable tool for the management of this resource.

Keywords: Viticulture, climate change, water use efficiency, water stress.

1. Introduction

Climate change and the increasing water scarcity pose a great challenge for agricultural development, including viticulture. Especially, for current viticulture under semi-arid to dry sub-humid climates, in which the irrigated area has significantly increased in various countries as a way to alleviate the production and quality-constraining effects severe water stress cause (Flexas et al, 2010). Even more in Spain, given the large surface area occupied by vineyards, the risk of overexploitation of water resources by vine-growing is more of a concern due to the undesirable economic and environmental impacts water shortage bears (Pulido-Velazquez et al, 2008). It is therefore necessary to develop strategies that allow a more rational use of water and guarantee the environmental sustainability of viticulture. This is not a simple task, since the response of grapevines to water availability and water use efficiency can be highly variable depending on genetic, environmental, edaphic and management factors, as well as their interactions (Medrano et al, 2015).

This work is part of the WANUGRAPE4.0 project, which aims to capitalize on previous knowledge acquired in preceding projects by research teams from all over Spain. With the information gathered in these experiments, a meta-analysis was carried out to evaluate the influence on vegetative development, yield and grape composition of the management of vine water status, by decreasing the level of water stress during the growing season.

2. Material and methods

Creation of the database - A database compiled during the AGL2017-90759-REDT project "New advances in viticulture - RedVitis 2.0" has been extended within the WANUGRAPE4.0 project. In total, information from 41 trials conducted by the research groups participating in the project was collected. The trials were conducted between 1996 and 2020 in nine Spanish Autonomous Communities (Galicia, Navarra, La Rioja, Catalonia, Balearic Islands, Castilla la Mancha, Castilla y León, Valencia, and Extremadura). The database includes information on vegetative development, yield, grape quality characteristics at harvest and water potential, for around 1,400 replicates, covering 19 varieties (9 whites and 10 reds) over a wide range of soil and climate and growing conditions that can be regarded as fairly representative of the Spanish viticulture.

Stem water potential values over the season from each of the replicates within each experiment were used to classify them into five stress levels as defined by Baeza (2017): No Stress (>-0.411 MPa), Mild (-0.674 to -0.411 MPa), Moderate (-0.936 to -0.674 MPa), High (-1.2 to -0.936 MPa), and Severe (<-1.2 MPa). In a second step, within each trial and study year, all replicates classified within the same stress level were grouped into observations. The mean and standard deviation of the replicates included in each observation were calculated for the response variables analyzed (yield, pruning wood weight, soluble solids content (TSS) and titratable acidity).

Statistical analysis - Response ratios (*RR*) were calculated to quantify the effect of increasing the stress in one level within each trial and year by means of Eq 1:

$$RR = \ln ln\, X_{ls} - \ln ln\, X_{hs} \quad \text{(Eq 1)}$$

where X_{ls} is the mean value of the response variable for the lower stress level and X_{hs} is the mean value for the immediately higher stress level (e.g., increasing from High to Severe stress). Then, a weighting factor ω was calculated for each *RR* based on Eq 2:

$$\omega = \frac{1}{\frac{s_{ls}^2}{n_{ls}\times X_{ls}^2} + \frac{s_{hs}^2}{n_{hs}\times X_{hs}^2}} \quad \text{(Eq 2)}$$

where *s* is the standard deviation and *n* the number of replicates included within each observation. The weighted mean response ratio (RR_p) was calculated with Eq 3:

$$RR_p = \frac{\sum_{i=1}^{j} \omega_i \times RR_i}{\sum_{i=1}^{j} \omega_i} \quad \text{(Eq3)}$$

where *j* is the total *RR* calculated over the set of trials and years, ω_i is the weighting factor of the RR_i response ratio. The percent of change (*C%*) of the investigated variables induced by the increase of the stress level were calculated with Eq 4:

$$C\% = \left(e^{RR} - 1\right)\times 100 \quad \text{(Eq 4)}$$

The results were plotted in *R* (R Core Team, 2022), by means of *RStudio* (RStudio Team, 2020) using the *forestplotter* 1.0.0 package (Dayimu, 2022).

3. Results and discussion

The replicates included in the WANUGRAPE4.0 database were grouped into ≈500 observations. The number of observations comprising the bottom and top levels of each comparison was uniform in all cases (Figures 1 and 2). In general, the step from a situation of 'No stress' to one of 'Mild stress' was the one for which the smallest number of observations was available (between 30 and 48 observations). Conversely, for the other responses the number of observations was much higher (between ≈100 and ≈250), with the central steps (from 'Mild' to 'Moderate' and from 'Moderate' to 'High') being the best represented.

For pruning wood weight and yield (Figure 1), increasing the water stress by one level always had a significant effect ($p < 0.05$), as the intervals at the 95% confidence level for the respective response ratios never contained the zero (RR = 0). The patterns and intensity of responses for pruning wood weight and yield were very similar, since increasing the water stress level always decreased the magnitude of both. Notwithstanding, the largest decrease was observed for the step from 'Moderate' to 'High' stress, being ≈ -26±3%, while for the rest of the cases the change was much less, specifically, between ≈ -5±4% and -15±3%, with no significant differences among them. In the case of TSS (Figure 2), moving from 'Moderate' to 'High' stress decreased its magnitude by -0.74% (±0.5%), which means average increases of between 0.1 and 0.3 ºBrix in most cases, while for the rest of the cases the decrease in the water stress level resulted in TSS increases of up to 1.5%, which means up to +0.5 ºBrix. In the case of titratable acidity, the change from 'High' to 'Severe' stress was 1.4% (±1%), while in the rest of the cases it decreased between -2.6% and -5.2%.

Therefore, in relation to vine growth and yield, increasing water stress always has a negative effect. The intensity of this effect can be considered constant (as the confidence intervals cover a very similar range) at both extremes, i.e., for stress increases when it is still mild or is already high. However, when shifting from moderate to high stress levels, much more severe reductions in growth or yield can be expected, around 2.5-3 times more intense than in the other situations. A similar pattern is found for the grape content in soluble solids, although in this case increased water stress has been enhanced TSS accumulation in berries at an almost constant rate except when moving from moderate to high stress, where it is slightly impaired. Finally, in the case of acidity, the pattern differs from the other parameters. Increases in stress up to moderate levels have a strong depressive effect on titratable acidity, which becomes less intense (even reversing) in changes with higher levels of stress.

4. Conclusions

The results show the overall impact of water status management on the agronomic response of the vineyard and constitute a valuable tool for water management in these agroecosystems and the development of decision support systems.

5. Acknowledgments

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6. Litterature cited

Baeza, P. (Coord), 2017. Guía de campo de viticultura. Editorial Agrícola. Madrid

Dayimu, A., 2022. Forestplotter v0.19. Create flexible forest plot. R-package. URL https://cran.r-project.org/package=forestploter.

Flexas, J., Galmés, J., Gallé, A., Gulías, J., Pou, A., Ribas-Carbo, M., Tomàs, M. and Medrano, H., 2010. Improving water use efficiency in grapevines: potential physiological targets for biotechnological improvement. Aus. J. Grape Wine Res. 16: 106-121.

Medrano, H., Tomás, M., Martorell, S., Escalona, J.M., Pou, A., Fuentes, S., Flexas, J. and Bota, J., 2015. Improving water use efficiency of vineyards in semi-arid regions. A review. Agron. Sustain. Develop. 35(2): 499-517.

Pulido-Velazquez, M., Andreu, J., Sahuquillo, A. and Pulido-Velazquez, D., 2008. Hydro-economic river basin modelling: The application of a holistic surface–groundwater model to assess opportunity costs of water use in Spain. Ecol. Econom. 66(1): 51-65.

R Core Team, 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

RStudio Team, 2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

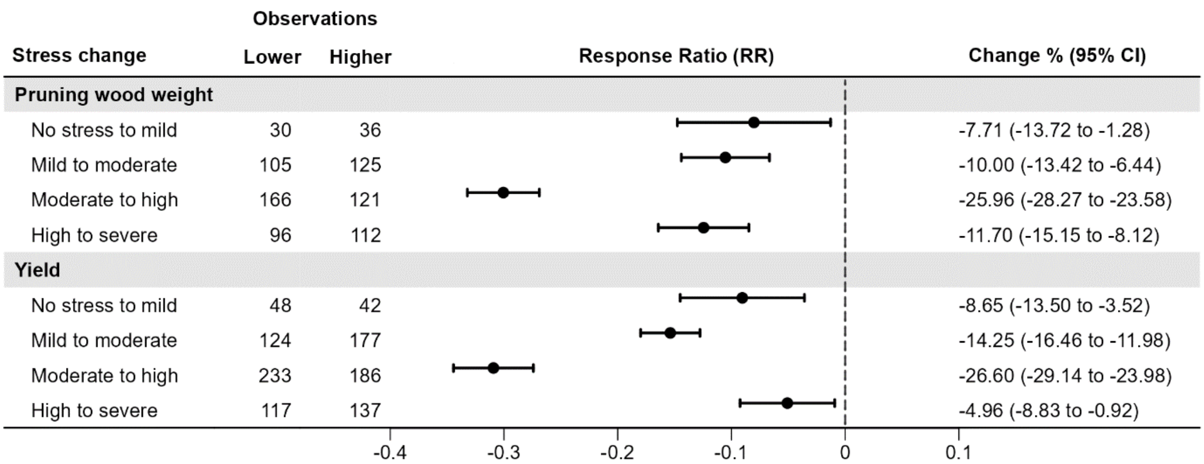

Figure 1: Forest plots for the effects of increasing water stress level on pruning wood weight and vineyard yield. Horizontal bars stand for the mean value of the response ratio (RR) and the 95% confidence interval (CI), thus effects are significant at *p*=0.05 when bars do not cross the zero-response ratio vertical dashed line.

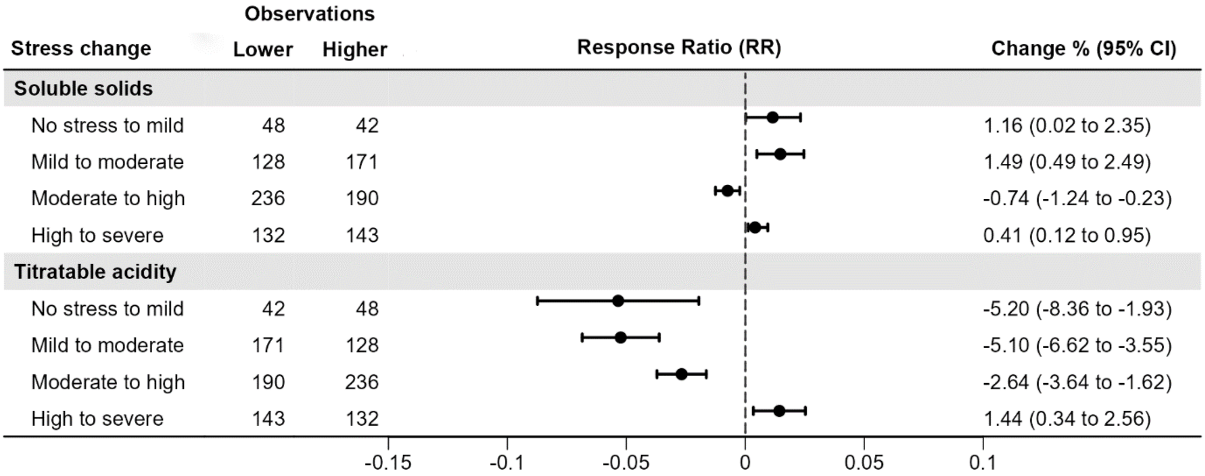

Figure 2: Forest plots for the effects of increasing water stress level on the soluble solids content and the tritratable acidity of berries. Horizontal bars stand for the mean value of the response ratio (RR) and the 95% confidence interval (CI), thus effects are significant at *p*=0.05 when bars do not cross the zero-response ratio vertical dashed line.